Perceptions about Design for Construction Worker Safety: Viewpoints from Contractors, Designers, and University Facility Owners

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Abstract: Decisions made before construction can affect safety on the construction site, either positively or negatively. This was observed from past research that identified the link between design decisions and fatalities. The concept of implementing design decisions that positively affect safety falls under the general concept of prevention through design (PtD), which attempts to identify and mitigate hazards early in the design process to eliminate the risks of injury or damage during construction. Prevention through design is practiced in other countries, primarily through legislation. The objective of this paper is to present the results of a survey that was conducted to identify construction industry stakeholders' views on the concept of PtD and gauge the possibility for implementing PtD in the U.S. construction industry through either legislation or other means. Four distinct groups were surveyed: engineers, architects, contractors, and owners. Within this study, PtD was described and introduced to survey participants as design for construction worker safety (DCWS) to differentiate PtD efforts in construction from efforts in other industries. The survey consisted of questions that asked about the industry's knowledge of PtD and the extent of PtD practice in the United States, participants' opinions on designer and owner safety knowledge and perceptions, and obstacles and enablers for designer participation in construction safety. The responses from the various groups were compared to identify the groups that are more receptive to the idea of designer participation in construction worker safety. The results showed that architects were the least receptive to the idea, whereas the other groups were more likely to be supportive, with some hesitations. Architects and engineers identified the existence of economic, legal, and contractual obstacles for designers to practice DCWS, whereas contractors only identified economic obstacles. No enablers were identified by any group. The research contributes additional information that can be used by construction industry practitioners and organizations desiring to expand and optimize PtD implementation in the United States. The research results can be used by project teams to plan for PtD education and training efforts on projects and by construction industry organizations to develop PtD diffusion strategies. **DOI: 10.1061/(ASCE)CO.1943-7862.0001067.**

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Introduction

The U.S. construction industry has a disproportionate injury and illness rate and fatality rate when compared with other industries. In 2011, the construction industry employed approximately 7% of the total U.S. workforce, yet it accounted for 15.7% of all occupational fatalities. Specifically in 2011, there were 721 deaths in construction, second only to transportation with 733 (BLS 2013). The number of fatalities in construction in 2012 increased to 806, surpassing transportation, which had 741 fatalities.

The cause of accidents, according to several research projects, has been attributed to factors that are distant to the construction work site. A European study has shown that 60% of fatalities in construction are caused by decisions made "upstream" from the construction site (European Foundation 1991). Similarly, a study from Australia showed that lack of planning and design decisions can influence 63% of fatalities (NSW Workcover 2001). Finally, a study in the United States (Behm 2005) has also shown that 42% of construction site fatalities can be linked to design. The link between design and construction fatalities urged many countries to address the issue by enacting legislation to encourage and/or require designer involvement in construction worker safety (EEC 1989, 1992; INSHT 1997; Her Majesty's Stationery Office 2007). In the United States, attempts to enact similar federal legislation have been defeated in the House of Representatives, the Senate, and in state governments (Gambatese 2000a; Behm 2005). Thus, alternative methods are needed to educate designers and other industry participants about the benefits of designer involvement in construction safety.

The idea of designer participation in construction safety falls under the broader concept of prevention through design (PtD), which is described by Manuele (2008) as "the integration of hazard analysis and risk assessment methods early in the design and engineering stages, and taking the actions necessary so that risks of injury or damage are at an acceptable level." The key phrase in the above definition is "early in the design and engineering stages," which encourages and expects designers to find any possible sources of hazards to personnel, facilities, and the environment, caused by industrial processes, construction, and products, early during their design phase and eliminating these hazards before production or use. Also, the term *acceptable level* is equally important in the

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definition and is defined as the level at which the probability of a hazard-related incident and the severity of possible damage are as low as practically possible for each particular situation (Manuele 2009).

In this paper, the concept of PtD is described as design for construction worker safety (DCWS) to differentiate it from PtD efforts in other industries and to highlight efforts in construction and for construction workers.

Problem Statement and Research Objectives

A lack of understanding of what is involved when designers are asked to practice DCWS exists within the current U.S. construction industry (Behm 2004; Toole 2005). In addition, there is great objection to designers practicing DCWS from some design professionals within the industry (Behm 2004; Toole 2005, 2011). Future efforts needed to promote DCWS practice in the United States will initially require identifying the status quo within the industry to determine how to proceed and be successful. Past research that investigated DCWS, and PtD in general, in the United States incorporated small sample sizes (Hinze and Wiegand 1992; Behm 2004). The authors believe that DCWS should be practiced throughout the United States. Therefore, more studies should include input from multiple perspectives across the country. The link between design decisions and fatalities has been observed (NSW Workcover 2001; Behm 2005; Gibb et al. 2014), and DCWS would be ideal in reducing the number of fatalities in the U.S. construction industry.

The primary objectives of the research presented in this paper are to gauge current understanding, interest, and concerns for the potential of DCWS implementation throughout the United States by construction industry participants. To achieve these objectives, a survey was developed and distributed to four groups of construction industry professionals in the United States. These groups were designers (architects and engineers), owners, and construction contractors. Their responses were tabulated and compared to examine whether the groups have differences in viewpoints on the DCWS concept and whether they have different concerns regarding DCWS implementation in the United States. The results of the survey can be used to determine the course of action and method necessary to increase awareness and interest for DCWS implementation by the U.S. construction industry. Such a study of this magnitude has not been conducted in the United States, nor have the opinions of industry participants been compared side by side on the topic of PtD. Some anecdotal evidence exists regarding the industry viewpoints on PtD, but no study has dealt with the construction industry's views as a whole.

Literature Review

As mentioned previously, the construction industry in the United States is one of the most dangerous industries, with high incidence rates in both fatalities, and illnesses and injuries (BLS 2013). As observed in Fig. 1, the latest figures for fatalities show that the number of incidences, and the incidence rates are on the rise again.

A direct comparison of the number of construction industry fatalities in the United States with that in other countries would not be accurate because of differences in construction market size between countries, so the incidence rates for fatalities are used instead. The fatality incidence rate is the equivalent number of deaths per 100,000 full-time workers per year (BLS 2013). As observed in Table 1, the incidence rate for fatalities is lower in other countries than in the United States. (WSHC 2013; Eurostat 2014; NOH&SC 2014). The country with the lowest rates is Great Britain, with incident rates of 1.78–2.5 for the years 2008–2011. A better comparison for the relationship of the U.S. fatality incidence rates with a territory of similar population and economic activity would be with all of the European Union (EU) countries as a whole. Between 2008 and 2011, the annual incidence rates for the EU27, the 27 EU member countries at the time, were 7.94, 7.21, 6.59, and 6.18, respectively. All of the countries that are listed in Table 1, except the United States, have legislation in place that requires designer participation in construction worker safety.

DCWS and Hierarchy of Controls

Construction projects have a lifecycle consisting of five phases: conception, design, build, operate/maintain, and eliminate/recycle/revise. Designer involvement during this lifecycle is only for a limited time, primarily during the design phase. This short involvement reduces their ability to influence safety, so it is important for them to provide input early in the project delivery process. The ease of addressing safety is greater when it happens early in the project

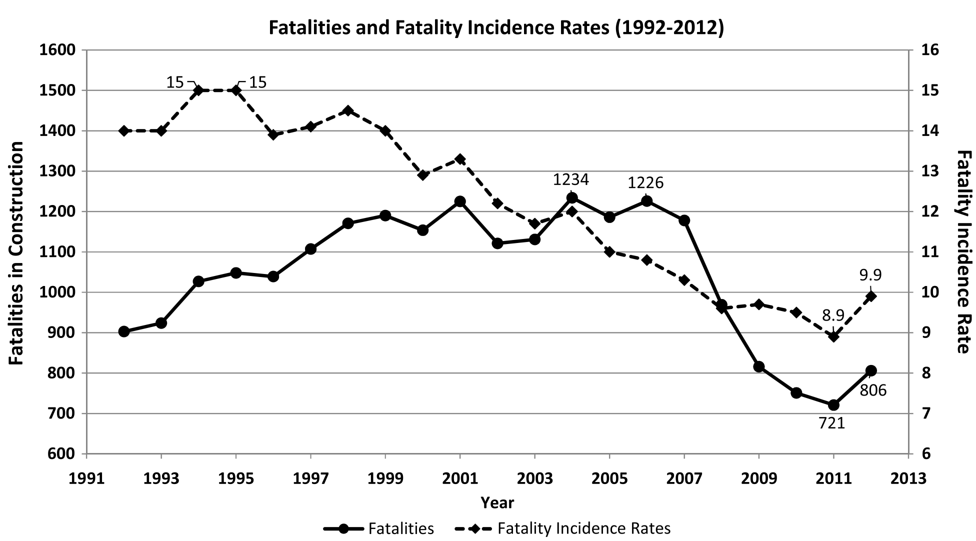

Fig. 1. Fatalities and fatality incidence rates (1992–2012) (data from BLS 2014)

Table 1. Annual Incidence Rates for Fatal Accidents in the United States and Other Countries (Data from WSHC 2013; Eurostat 2014; NOH&SC 2014; BLS 2013)

	Fatality incidence rate			
Country	2008	2009	2010	2011
Australia	3.81	3.61	4.03	3.97
Austria	7.48	14.19	7.64	3.57
Belgium	11.35	7.11	7.36	5.63
Denmark	5.69	4.44	5.11	4.4
Finland	3.27	4.65	4.01	2.27
France	4.99	6.98	6.08	6.92
Germany	4.81	3.5	3.15	5.05
Great Britain	1.78	1.9	2.36	2.5
Ireland	5.43	5.97	4.18	4.64
Italy	9.27	9.23	9.22	7.75
Netherlands	9.52	5.16	2.35	1.73
Norway	4.84	NA	4.14	4.97
Singapore	6.9	8.1	8.1	5.3
Spain	9.95	8.94	7.99	10.36
Sweden	5.57	3.08	4.61	3.23
United States	9.6	9.7	9.5	8.9
EU27	7.94	7.21	6.59	6.18

lifecycle (Manuele 2009), the effort required is less, and the people required to make safety decisions are fewer. If a project requires changes to address safety considerations later in its lifecycle, there is a greater amount of coordination and work to be performed. This increased work also leads to higher costs for implementing safety measures (Manuele 2009).

Safety considerations and safety measures or controls can be placed in a hierarchy according to their effectiveness. This hierarchy of safety controls has six levels according to Manuele (2009). The levels in order from highest to lowest rank are: (1) elimination; (2) substitution; (3) engineering controls; (4) warning systems; (5) administrative controls; and (6) personal protective equipment. Controls that are higher in rank are considered to be more reliable, effective, and of better financial value. Controls of a higher level are also preventative in nature, and their successful implementation does not rely on the performance of field personnel. They are also less likely to be rendered ineffective. To implement these higher-level controls, designer involvement is necessary.

Key Construction Industry Groups and Their Role in Safety

Previous literature has shown that construction industry groups such as contractors/subcontractors, engineers/architects, and owners can play a role in and influence safety on the construction site, each in their own way. A detailed summary of key literature is provided in the following.

Contractors/Subcontractors

The traditional view on construction safety is that it lies solely on the contractor. This view is further reinforced by Occupational Safety and Health Administration (OSHA), which states that employers are responsible for providing a safe place for their workers to work, without any mention of influence from designers and owners (Hinze and Wiegand 1992). Furthermore, five of the eight behavioral root causes of accidents identified by Toole (2002) are associated with unsafe working conditions, which are generally under the responsibility of the contractor because they indicate a lack of safety management. In addition, traditional contracting methods, such as design-bid-build, create a solid separation between the various phases of a construction project, separating other construction industry participants from the responsibility for construction worker safety, and by default any interest in improving safety.

Owners

Owners are the construction stakeholder group that drives the need for construction to take place. By tradition, owners do not take an active role during the construction process, primarily because of their lack of expertise and personnel available to oversee construction. In general, designers act as the owners' agents and take over that role (Hinze 2001). Recent litigation proceedings have shown that increasingly owners are being held responsible for accidents that occurred on work sites, suggesting that there is a need for a more active involvement by owners (Nwaelele 1996; Hinze 2006; Huang and Hinze 2006).

Such involvement could be in the form of increased expectations and requirements during design and planning, such as scheduling expectations, eliminating toxic substances in materials used for construction, requiring that sustained overtime and night work be avoided, and imposing of limits on worker numbers on site. These demands and expectations should also be accompanied with a verbalized clear position on safety commitment by the owner or owner representatives to all project participants and their inclusion in formal project documents and contracts. An owner's safety position can also be addressed during planning and design by selecting designers who have knowledge and are actively involved in safety by insisting that designers address construction safety during design and by providing the necessary compensation for such involvement. In addition, owners can include safety criteria and performance during the selection process for a contractor. Such criteria can be, but not limited to, the experience modification factors, injury and incidence rates, loss ratios, OSHA citations and fines, and performance records. Furthermore, during construction, owners can participate in safety meetings, conduct their own safety inspections, and participate in safety training (Gambatese 2000b).

Previous research has been conducted that targeted owners and their knowledge of DCWS implementation on their projects (Hinze 1994). As part of surveys of owner firms with large construction budgets, the owners were asked if designers on their projects addressed construction worker safety in their designs. The most prevalent response (by 45% of owners) was that worker safety is not considered. This was followed by 29% indicating that safety for specific items is occasionally addressed; however, these items were generally considered to be those related to both construction worker safety and safety of the "end user." It was promising to find that 16% of the owners surveyed indicated that safety is addressed, and 10% stated that safety may be addressed in their designs in the future.

Designers

Safety focus for designers has traditionally been exclusive to the end-user personnel of the facility being designed, with disregard for the personnel constructing it. The reasons given for this lack of involvement include lack of training and education to address worker safety concerns, as well as the inability to direct worksite activities (Gambatese 2000a).

The influence of design decisions on construction site safety though is often misunderstood by industry participants. Designers are responsible for design decisions. Each design decision, such as connection details, material selection, and components used for the

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construction of a project, influences and affects construction methods used in the field. Hinze (2006) argues that the misconception that designers should not be responsible for construction safety simply because they do not instruct contractors on the means and methods but only the end result is false. Research has shown that designers have the capabilities to address safety. Toole (2005) describes five methods with which designers can influence and positively affect construction safety:

1. They can review for safety much like they review for functionality during the peer review process of the design by including in that process additional checks that would ensure that the design addresses construction worker safety. Toole (2005) suggests that this review be performed by qualified construction professionals within the design firms or by external consultants. Examples of such checks could be but are not limited to reducing roof pitches to a reasonable level, or by ensuring the bottom of window openings are 42 in height, satisfying OSHA requirements for fall protection.
2. They can create design documents for safety and mark in the construction documents potential safety concerns. Again Toole (2005) suggests that in addition to the safety review process of design documents, designers can include specific details in their design that would address construction safety concerns. Such inclusions can be locations on the structural frame of a building that can provide sufficient strength to serve as tie off points or erection sequences for prefabricated steel or concrete structures.
3. They can assist in the selection of a contractor by reviewing the contractor's safety record and procedures much like they review cost and schedule. According to Toole (2005), designers often provide assistance to owners in the soliciting and reviewing bids from contractors during the bidding process, and in addition to the drawings and specifications, they also create the requests for proposals (RFP). Designers can request that contractor safety records and safety plans be part of the criteria for selecting contactors for projects.
4. They can review submittals for safety. Toole (2005) suggests that designers can review contractor "design-related documents," such as shop drawings and layout plans, to ensure that safety goals of the project are met.
5. They can inspect construction sites for possible safety concerns. Designers are required periodically to inspect construction sites to ensure compliance to specifications and drawings. Toole (2005) also suggests that designers can monitor sites for compliance to safety requirements indicated by the contact documents.

Methodology

The researchers selected the use of a survey to collect the information from the four construction industry groups.

Design of Survey Questionnaires

Three similar surveys were developed and distributed to the following industry groups: owners, designers (architects and engineers), and contractors. The surveys were designed to gather viewpoints concerning the DCWS concept from the participants, in particular, their level of knowledge of the DCWS and PtD concepts and their perceived obstacles and enablers for DCWS implementation by designers in the United States.

Each survey had four sections. The first section (Section A) consisted of questions for identification and differentiation of the participants with questions regarding the type of work performed by the participants' firm/organization and their work experience. The information solicited included the name of their organization, their title, years of experience in construction and design, types of project delivery methods their organization uses, and the types of structures and projects they construct or design. From these questions, only the years of experience and the size of the firm were used in the analysis. These questions are marked as Aexp and Asize.

The second section of the survey (Section B) aimed at identifying previous knowledge the participants might have had concerning the DCWS concept (B1) and participation of their firm/organization in DCWS (B2); whether their firm/organization has guidelines for DCWS participation (B3); whether their firm/organization was asked to review design for construction safety (B4); and whether they participated in preconstruction meetings where construction worker safety was discussed (B5). A definition and description of DCWS were provided with the survey questionnaire for their reference. Participants were also asked to identify the reasons for their firm's decision to start practicing DCWS.

The third section of the survey (Section C) included a series of Likert-type questions in which participants were asked to identify their level of agreement or disagreement with statements regarding designers' and owners' knowledge of safety in the construction industry. The statements addressed the level of understanding of each group concerning construction site operations (C1a, C2a), hazards to construction workers (C1b, C2b), capacities and opportunities for education in construction safety (C1c, C2c), and possible involvement/capability of involvement in construction safety (C1d, C1e, C2d, C2e). In this section, participants were asked whether they agree that the construction industry is a hazardous industry (C3a); whether only construction contractors are currently involved in reducing construction site hazards (C3b); and whether all construction site hazards are taken care of by construction contractors (C3c). In addition, the survey participants were asked to state their agreement on whether decisions made during project conception (C3d), design (C3e), and construction (C3f) affect construction worker safety. They were also asked whether their firm would be supportive of legislation for designers to practice DCWS (C4a) and whether their firm would be supportive of the DCWS concept through legislation if designers were legally protected from liability in practicing DCWS (C4b).

The fourth section of the survey (Section D) asked participants to state whether there are obstacles (D1a-f) or enablers (D3a-f) for designers to practice DCWS, and if that was the case, the respondents were asked to identify the obstacles and enablers. Because of the research method chosen (online survey), the obstacles and enablers are those that are perceived by the designers on the basis of their current point of view and experience with DCWS. Further empirical research would be needed to verify that the obstacles and enablers identified are accurate and all-inclusive.

Sample Framework

A comprehensive study investigating the U.S. construction industry's viewpoints on the topic has not been conducted. Previous studies such as the one conducted by Behm (2004) used viewpoints from 19 designers in California, Oregon, and Washington, whereas a study by Hinze and Wiegand (1992) included only 23 design firms. Furthermore, inherent differences in design practices may exist between states, which arise from differences in code requirements, prevalent materials used for design/construction, and contractual practices. To make sure that these differences do not bias the results of the survey, the researchers decided to include a sample of participants that had geographic diversity.

To ensure this geographic diversity of the responses, the nine U.S. Census Bureau Divisions (USCB 2011) were used to select the states from which survey participants were selected. The nine U.S. Census Bureau Divisions and their included states are as follows:

1. Pacific Division—Alaska, California, Hawaii, Oregon, and Washington
2. Mountain Division—Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming
3. West North Central Division—Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota
4. West South Central Division—Arkansas, Louisiana, Oklahoma, and Texas
5. East North Central Division—Illinois, Indiana, Michigan, Ohio, and Wisconsin
6. East South Central Division—Alabama, Kentucky, Mississippi, and Tennessee
7. South Atlantic Division—Delaware, District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, and West Virginia
8. Middle Atlantic Division—New Jersey, Pennsylvania, and New York
9. New England Division—Connecticut, Maine, New Hampshire, Massachusetts, Rhode Island, and Vermont

To achieve a majority from each division, at least half of the states were randomly selected. Twenty-nine states were chosen: Alaska, Arkansas, Colorado, Connecticut, Delaware, Georgia, Idaho, Illinois, Kansas, Kentucky, Maine, Maryland, Missouri, Nebraska, Nevada, New Hampshire, New Mexico, New York, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, South Carolina, South Dakota, Tennessee, Virginia, Washington, and Wisconsin.

The identification of participants from the construction industry groups to respond to the surveys was performed in a variety of ways because of the variability of the available contact information. Specifically, the selection of individuals to distribute the surveys was as follows.

Owner Population Selection

Requests were made to owner groups in the United States to distribute the survey to their members, but none of the contacted organizations were willing to disseminate it to their members. Consequently, the researchers decided to approach and contact a unique and more accessible owner type—U.S. higher education institutions. Universities and colleges in the United States, depending on their size, perform multiple construction projects at any given time. The types of projects include facilities ranging from educational and residential buildings to power plants, research facilities, sports facilities, civic buildings, and hospitals. The universities also have experience with a variety of project delivery methods, which include design-bid-build, design-build, construction management/general contractor, and build-operate-transfer, among others.

The researchers used Peterson's Student Edge website (Peterson's 2011) to obtain a directory of all the universities in the United States. Among other criteria, the universities in the directory are categorized according to their ownership (public/private) and the size of their student body. The website separates universities into four different size categories:

1. Large: more than 15,000 students
2. Midsize: 5,000–15,000 students
3. Small: 2,000–5,000 students
4. Very small; less than 2,000 students

For the purposes of this research, very small universities were not surveyed. For all other university sizes in the 29 selected states, a contact person within the office of facility services or any other equivalent university department that would be responsible for the supervision and management of construction contracts on their respective campus was identified through internet and university directory searches. A total of 554 universities were identified in the sampled population, and personnel from 345 (62%) of these universities were successfully contacted.

Contractor Population Selection

A list of construction contracting firms was obtained from the membership directory of the Associated General Contractors of America (AGC). The AGC website maintains a directory of construction firms, and for the purposes of this investigation, general contractors that participate in building construction were selected. The filters used to identify these firms from the AGC directory were commercial, healthcare, manufacturing, education, and lodging/multifamily residential projects.

Through various internet searches, contact personnel in each construction firm to respond to the survey were identified. Targeted participants were those who had extensive construction experience and were key management figures in their firm. From the 29 selected states, 1,617 firms were identified, and personnel from 891 (55%) of these were successfully contacted.

Designer Population Selection

Two groups of designers were identified: architects and engineers. The sample population for the architects was generated by using the American Institute of Architects (AIA 2011) database, in which the AIA lists and provides contact information for all of their members according to their state of residence. A random sample of architects was generated from each state, and a survey was sent to each selected architect. From the 14,905 registered AIA architects in the United States (AIA 2011), 1,059 architects (7%) were successfully contacted.

The sample population for engineers was obtained from the American Council of Engineering Companies website (ACEC 2011). The council's website maintains a directory of engineering companies practicing in the United States stratified according to size and state. The directory also allows visitors to the website to filter the companies according to the market served. For this study, the researchers filtered the list according to the markets that are used in the construction of buildings, the main area of interest in the study, such as barracks, dormitories, and civic buildings. The website separates firms into the following six different sizes:

1. Small: 1–30 employees
2. Medium: 31–75 employees
3. Medium-large: 76–150 employees
4. Large: 151–499 employees
5. Extra large: 500–999 employees
6. Extremely large: more than 1,000 employees

Through internet searches, a contact personnel in each engineering firm was identified to respond to the survey. These individuals had extensive design experience and were key management figures in their firms. From the 29 selected states in all six firm sizes, 2,131 firms were identified, and personnel from 1,291 (58%) of these firms were successfully contacted.

Survey Distribution

The program *LimeSurvey* was used to administer the surveys online. The responses were stored on servers of Oregon State University–College of Engineering. Subsequently, the responses

Table 2. Summary of Responses and Response Rates

Response analysis	Owners	Architects	Engineers	Contractors	Total
Responses	121	221	244	179	765
Contacted	345	1,059	1,243	891	3,538
Response rate (%)	35.1	20.9	19.6	20.1	21.6

were downloaded for analysis after erasing any identifying information from participants.

Results

Of the 3,548 individuals who were successfully contacted for the various surveys, 765 responded (21.6%). These included 121 owners (35.1%), 221 architects (20.9%), 244 engineers (19.6%) and 179 contractors (20.1%). This information is shown in Table 2. The average number responses from each state was 26.3, with a minimum of 9 (Maine) and a maximum of 42 (New York)

The survey participants had extensive experience in the construction industry, and the authors wanted to capture that experience in the survey responses. Specifically, 73% of all engineers, 79.2% of architects, and 81.1% of contractors who participated in the survey had at least 20 years of experience in construction and/or design.

Knowledge of DCWS is very minimal in the U.S. construction industry at the moment (Gambatese 2000a) as observed from the responses, with 20.5% of engineers, 5.4% of architects, 21.5% of owners, and 16.2% of contractors stating that they knew of DCWS before the survey. U.S. design professional participation in DCWS is low also, with only 19.3% of engineers and 5.4% of architects responding that their firm practices some form of DCWS in their designs. Examples of such practices include active practice of DCWS through focused reviews and project hazard registers and the use of expertise from construction personnel during the design process to implement means and methods. These results appear to be consistent with those from initial research on the topic conducted approximately 30 years ago. A small study based on a survey of design firms (23 responses) and firms conducting constructability reviews (12 responses) revealed that less than one-third of the design firms address construction worker safety in their designs, and less than one-half of the independent constructability reviews conducted address construction worker safety (Hinze and Wiegand 1992).

The existence of formal guidelines within design firms for reviewing for construction worker safety is also low, with only 9.8% of engineers and 3.2% of architects stating that such guidelines exist. Even if formal guidelines are rare, designers in the United States have been asked to address construction safety issues. Thirty-one percent of engineers and 10.4% of architects stated in their responses that their firm has been asked to do so.

All the industry groups that participated acknowledge to various degrees that decisions made before construction can affect construction worker safety. In this survey, the industry groups were asked to state their agreement or disagreement to the following statements:

1. Decisions made *before the design* of a project begins can help eliminate some construction worker hazards;
2. Decisions made *during the design* of a project can help eliminate some construction worker hazards; and
3. Decisions made *during the construction* of a project can help eliminate some construction worker hazards.

As observed in Fig. 2, 68.4% of the engineers, 47.5% of the architects, 59.5% of the owners, and 81.0% of the contractors stated that they either agree or strongly agree with the statement that "decisions made before the design of a project begins can help eliminate some construction hazards." Similarly, 77.9% of the engineers, 52.5% of the architects, 66.2% of the owners, and 86.6% of the contractors stated that they either agree or strongly agree with the statement that "decisions made during the design of a project can help eliminate some construction worker hazards." Finally, 86.5% of the engineers, 84.2% of the architects, 80.2% of the owners, and 92.2% of the contractors stated that they either agree or strongly agree with the statement that "decisions made during construction of a project can help eliminate some construction worker hazards."

Even though the majority of the construction industry professionals do agree that decisions made before construction affect construction worker safety, support for designer and owner participation in safety is low. As observed in Fig. 3, support for designers to be involved in construction worker safety was 53.7% from

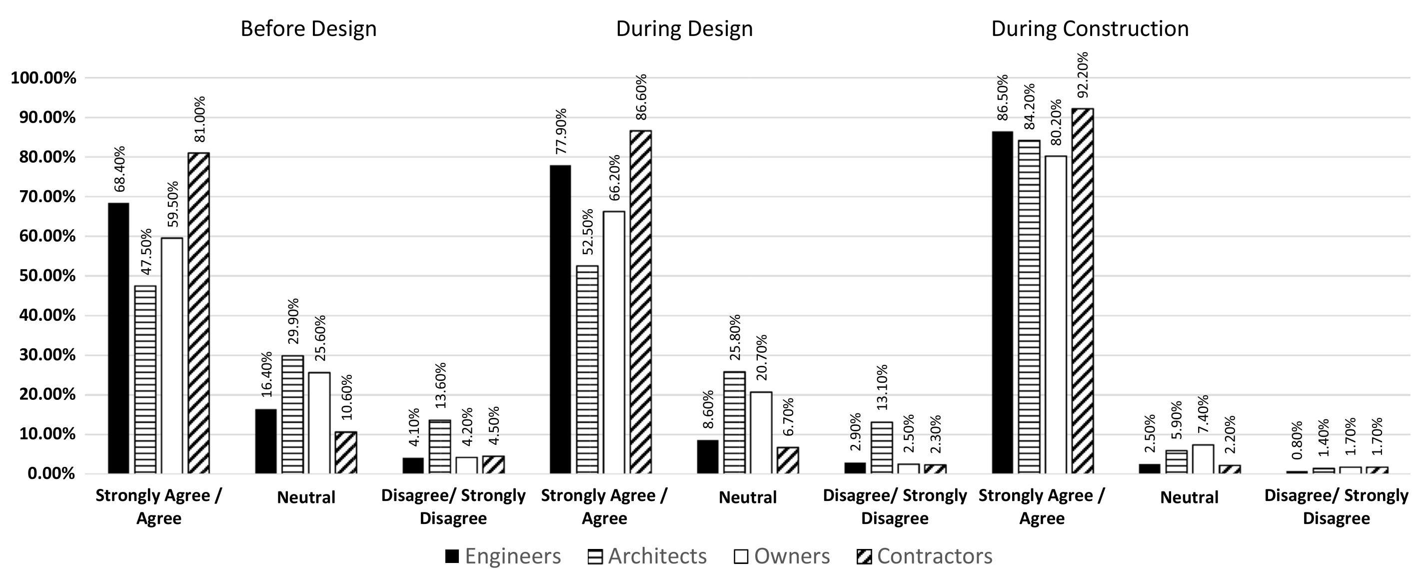

Fig. 2. Response to whether decisions made during the various construction phases affect construction worker safety

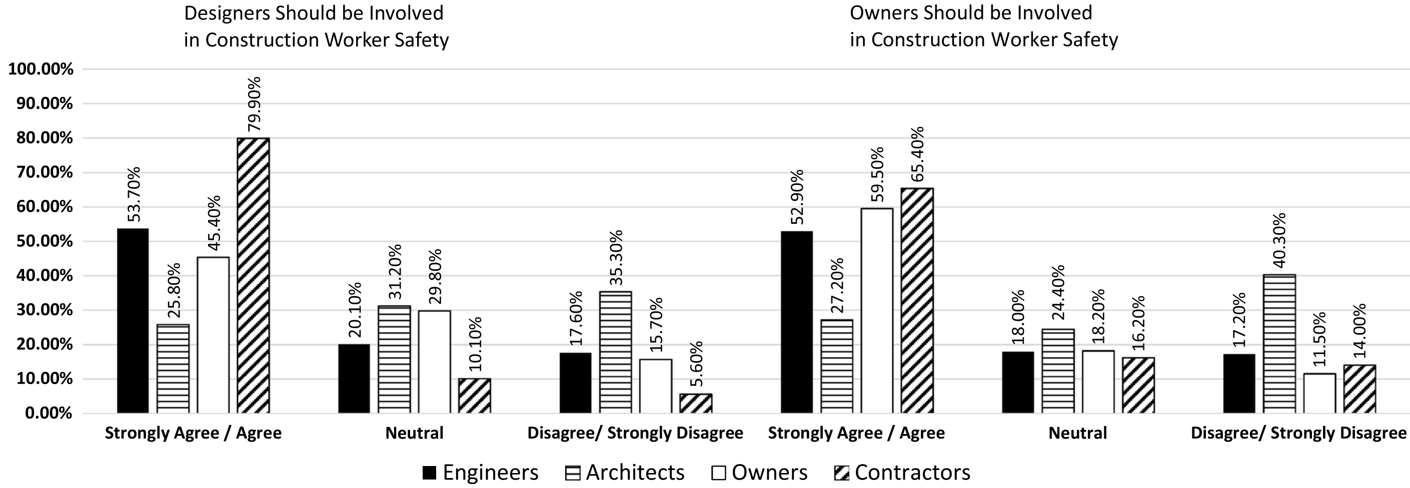

Fig. 3. Support for designers and owners to be involved in construction worker safety

engineers, 25.8% from architects, 45.4% from owners, and 79.9% from contractors. The support for owner involvement was 52.9% from engineers, 27.2% from architects, 59.5% from owners, and 65.4% from contractors. With the exception of the architect group, there seems to be significant support for an increased participation and involvement in construction worker safety by all construction industry members.

The survey participants identified obstacles and enablers in several areas that would either hinder or encourage designers to participate in DCWS. The percentages of respondents within each survey group who agreed with the existence of obstacles in a particular area are shown in Table 3, whereas the percentages regarding the existence of enablers are shown in Table 4. The majority of engineers and architects indicated that there are economic, contractual, and legal obstacles for designers to practice DCWS. The majority of contractors only identified economic obstacles, whereas the majority of owners did not agree on one particular area as being an obstacle. Regarding enablers (Table 4), there was no majority for any of the possible areas. *Majority* in this case is defined as at least half of the participants responding.

Table 3. Agreement with the Existence of Obstacles for DCWS Implementation by Designers (% of Respondents)

Obstacles	Engineers	Architects	Owners	Contractors
Regulatory (%)	32.0	46.6	30.6	19.6
Economic (%)	61.5	61.5	43.0	50.3
Contractual (%)	62.7	67.0	45.5	40.8
Legal (%)	55.3	62.0	37.2	38.5
Ethical (%)	9.8	22.6	7.4	9.5
Cultural (%)	36.5	38.9	27.3	30.2

Table 4. Agreement with the Existence of Enablers for DCWS Implementation by Designers (% of Respondents)

Enablers	Engineers	Architects	Owners	Contractors
Regulatory (%)	11.5	9.5	10.7	10.6
Economic (%)	17.6	13.6	10.7	20.7
Contractual (%)	18.0	13.1	11.6	24.0
Legal (%)	16.8	15.4	11.6	20.7
Ethical (%)	28.7	27.6	25.6	36.9
Cultural (%)	13.9	14.9	10.7	20.1

Analysis

In addition to frequency statistics, the analysis portion of the research involved the comparison of the responses between the various groups and the identification of what obstacles and enablers participants identified for designers to participate in construction worker safety. The researchers chose the following tests, using Microsoft Excel, to perform these comparisons: chi-square test for equality of odds, chi-square test for the 95% confidence interval, and ordered $2 \times k$ contingency tables. These tests are used extensively in the comparison of parametric data, and similar analysis for the comparison of information gathered from safety research has been performed in the past as is described as follows:

- Chi-square test for equality of odds (Ramsey and Schafer 2002): The Likert responses were truncated in 2×2 tables, allowing the comparison of two groups in relation to a response of interest and determining if the responses of the two populations differ. Such treatment of Likert responses is suggested in the literature by Siegel et al. (1988). An example of such truncation of the responses is shown in Fig. 4, in which the agreement to a particular statement is separated from the other possible responses and the differences between the odds ratios between the various groups can be compared. This test is marked as Xodd.
- Chi-square tests for the 95% confidence interval of the odds ratio (Ramsey and Schafer 2002): The 95% confidence interval for the odds ratio, described previously, can be calculated with this test. This test is marked as X95.
- Ordered $2 \times k$ contingency tables (Le 1998): The final statistical test that was applied to the responses was the ordered $2 \times k$ contingency tables for comparison of responses by taking into account a variable of increasing magnitude, such as increasing size of firm and years of experience. Such treatment of safety data was performed by López Arquillos et al. (2012) and by Camino López et al. (2008). One example of how the responses are organized before analysis is shown in Table 5. The frequency of the responses is ordered according to the size of the firm and the type of response. In this case a response of "Yes" or "No" was expected, and these frequencies are shown in the table as $Y_1 - Y_6$ and $N_1 - N_6$. This test is marked as 2k.

Table 6 shows how these tests were performed while comparing responses from the surveys. As an example, the size of the firm (Asize), and the experience of the participant (Aexp) were investigated against the responses to the Section B questions regarding

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Group A	XA_{SA}	XA_{A}	XA_{N}	XA_{D}	XA_{SD}
Group B	XB_{SA}	XB_{A}	XB_{N}	XB_{D}	XB_{SD}

	Strongly Agree / Agree	Other
Group A	$XA_{SA} + XA_{A}$	$XA_{N} + XA_{D} + XA_{SD}$
Group B	$XB_{SA} + XB_{A}$	$XB_{N} + XB_{D} + XB_{SD}$

Fig. 4. Example of truncation of Likert responses

Table 5. Example of $2 \times k$ Contingency Table

Size of firm	Yes	No
Small	Y_1	N_1
Medium	Y_2	N_2
Medium large	Y_3	N_3
Large	Y_4	N_4
Extra large	Y_5	N_5
Extremely large	Y_6	N_6

Table 6. Matrix of Question Comparisons

Question group	Question group				
	Asize	Aexp	B1-5	C1, C2, C3, C4	D1, D3
Asize	—	—	2k	2k	2k
Aexp	—	—	2k	2k	2k
B1-5	2k	2k	Xodd, X95	Xodd, X95	Xodd, X95
C1, C2, C3, C4	2k	2k	Xodd, X95	Xodd, X95	—
D1, D3	2k	2k	Xodd, X95	—	Xodd, X95

knowledge of DCWS and with the Likert-type questions (Sections C and D) by using the ordered $2 \times k$ contingency tables. A further analysis was conducted by assessing differences in the responses of the four different groups that were sampled (contractors, engineers, architects, and owners).

Prior Knowledge of DCWS

By observing the frequency statistics, it became very clear that construction industry participants are not aware of the DCWS in the United States. The architect group was the least aware group and was found to be 4.18 times more likely to not be aware of the concept than all other groups combined [p-value ~ 0.0; 95% confidence interval (CI) = 2.24–7.79]. Engineers with prior knowledge of the DCWS concept were also 2.04 times more likely to agree with the statement that "designers have adequate capacity and opportunities to be educated in construction worker safety" than designers who were not aware of DCWS (p-value = 0.017; 95% CI = 1.28–5.17). A possible reason for architects not being aware of any safety issues on the construction site might be attributed to the preexisting construction industry culture, which distances architects from any safety concerns during construction, and the assumption that all safety concerns on site are dealt with by the contractor, who has sole responsibility for the means and methods that bring a project from the design phase to completion.

Viewpoints also differ between individuals who work for a firm that participated in DCWS. These observations were more prominent with the engineer group. Engineers working for a firm that practices DCWS were 2.66 times more likely to agree to "designers participating in construction worker safety through design decisions" (p-value = 0.0131; 95% CI = 1.25–5.64) and 2.92 times more likely to disagree with the statement that "the nature of construction contracting does not allow designers to participate in construction worker safety" (p-value = 0.0461; 95% CI = 1.41–6.04). This participation in DCWS is much more prevalent in larger firms, where the engineers who stated that their firm practices DCWS were more likely to be employed (p-value = 0.0003). These observations might be attributed to these firms being more likely to have the capability and resources to educate their employees in construction safety.

Industry Knowledge and Safety Participation

To gauge any possible participation in construction safety, it is important to understand the variability in attitudes toward safety and safety understanding on construction sites by the various industry stakeholders. Specifically, both of the designer groups (architects and engineers) greatly agreed that "designers know how construction operation and procedures take place," with architects 2.59 times more likely than all other groups (p-value ~ 0.0; 95% CI = 1.82–3.69) and engineers 3.4 times more likely (p-value ~ 0.0; 95% CI = 2.39–4.85) than all other groups. Both groups also agreed that they have a clear understanding of "what constitutes a hazard to construction workers," with architects being 1.64 times more likely (p-value = 0.0019; 95% CI = 1.17–2.28) and engineers 2.24 times more likely (p-value ~ 0.0; 95% CI = 1.62–3.09) than all other groups. Contractors tended to disagree with the statements. Contractors were 6.84 times more likely to disagree (p-value ~ 0.0; 95% CI = 4.62–10.142) with the statement that "designers know how construction site operations and procedures take place" than all other groups combined and 5.96 time more likely to disagree (p-value ~ 0.0; 95% CI = 4.12–8.62) with the statement that "designers have a clear understanding of what constitutes a hazard to construction workers."

This attitude toward knowledge of the industry and its hazards to its workers was not equally reflected by all of the industry groups. When they were asked about opportunities to learn about safety, architects were 1.58 times more likely to disagree (p-value = 0.0056; 95% CI = 1.12–2.25) with the statement that "there are opportunities to learn about construction worker safety" than all other groups combined, whereas engineers were 2.12 times more likely to agree (p-value ~ 0.0; 95% CI = 1.42–3.18) with that statement than architects. Architects were also more likely to be in disagreement with the idea of being involved in construction worker safety. Specifically, they were 3.71 times more likely to disagree than the other industry groups (p-value ~ 0.0; 95% CI = 2.54–5.41), whereas engineers were 3.67 times more likely to agree than architects (p-value ~ 0.0; 95% CI = 2.44–5.50). Contractors were 3.58 times more likely to agree (p-value ~ 0.0, 95% CI = 2.20–5.82), and owners 2.57 times more likely to agree (p-value ~ 0.0; 95% CI = 1.59–4.18). Architects also perceive that the current nature of construction contracting does not allow them to participate in construction worker safety. Specifically architects responded that the nature of the industry is an obstacle 2.95 times

more often than all the other groups of participants combined (p-value ~ 0.0; 95% CI = 2.10–4.15).

Owners were 42.7 times more likely to agree with the statement that "owners know how construction site operations and procedures take place" (p-value ~ 0.0; 95% CI = 22.95–79.56). This value seems quite extreme but could be partly attributed to the nature of the owners who were surveyed. Facility services or other equivalent departments on university campuses are actively involved with the construction of their projects by supervising these projects with all the necessary experienced personnel.

When asked to specify if owners "have the capability to be educated in construction worker safety," owners were 10.85 times more likely to agree (p-value ~ 0.0; 95% CI = 6.41–18.37) than all other groups. Architects were 3.37 times more likely to disagree (p-value ~ 0.0; 95% CI = 2.34–4.86) that owners "have a clear understanding of what constitutes a hazard to construction workers." Regarding possibility for owner involvement in construction safety, architects were again more likely to disagree by 3.98 times than all other groups (p-value ~ 0.0; 95% CI = 2.76–5.73).

Construction Industry Hazards

All groups agreed that the construction industry is a hazardous industry, and there were no significant differences among the various groups regarding this statement. When asked the statement whether "contractors are the only group that is currently involved in reducing construction site hazards to construction workers," architects were 2.38 times more likely to agree with this statement than all other groups combined (p-value ~ 0.0; 95% CI = 1.70–3.33). A substantially less number of the survey participants from the other groups agreed with the statement, recognizing the current involvement of other participants in construction worker safety. Specifically, only 31.9% of engineers, 15.7% of owners, and 34.6% of contractors agreed with the statement. A similar attitude toward the statement that "all construction site hazards to construction workers are taken care of by construction contractors" was displayed by the architects. They were 2.38 times more likely to agree than all other groups (p-value = 0.0011; 95% CI = 1.20–2.34).

The survey participants showed some variability in their answers when asked "if decisions made before design can affect construction worker safety" (Fig. 2). In three groups (engineers, contractors, and owners), more than 50% of all participants agreed with the statement, but architects were 3.61 times more likely to disagree (p-value ~ 0.0; 95% CI = 2.04–6.39). The architects' agreement with the statement was 47.5%. Similarly, for "decisions made during design" (Fig. 2), architects had the lowest level of agreement with 52.5%, and they were 5.78 times more likely to disagree (p-value ~ 0.0; 95% CI = 2.98–11.201). Regarding decisions made during construction, there were no significant differences among the responses from each group.

Participation Though Legislation

Construction industry participants were also asked to state their support for legislation that would mandate DCWS participation by designers. Specifically they were asked to state their agreement with two statements: "My firm/organization would be supportive of proposed legislation for designers to start practicing DCWS," and "My firm would be supportive of the DCWS concept if designers were legally protected from liability in practicing DCWS." From the responses to these statements, it is clear that the group with the most support for legislation for DCWS was the contractor group. Their agreement with the first statement was 38%, which made them 3.91 times more likely to be in support of such legislation than all other groups combined (p-value ~ 0.0; 95% CI = 2.64–5.81). Engineers showed 15.6% agreement, architects 10.4%, and owners 11.5%.

With legal protection from liability for designers, the support for such legislation increased in the engineer group by 37.6–53.2%, in the architect group by 15.9–42.5%, and in the owner group by 10–21.5%. However, the support in the contractor group decreased by 6.1–31.9%.

Obstacles and Enablers

The obstacle areas that were identified in previous research were considered to be of varying importance by the survey participants. Regarding regulatory obstacles, architects were 2.38 times more likely to agree that they are in place (p-value ~ 0.0; 95% CI = 1.66–3.42) when compared with all other groups combined. Contractors on the other hand were 2.50 times more likely to disagree that there are regulatory obstacles in place for designers to practice DCWS (p-value = 0.0004; 95% CI = 1.54–4.06).

When participants were asked about economic obstacles, the engineers appeared to be different than all the other groups. The engineers were 1.72 times more likely to agree (p-value = 0.0013; 95% CI = 1.18–2.50) that economic obstacles exist. The area of contractual obstacles was recognized by both engineers and architects as a concern. Specifically, architects were 2.24 times more likely to agree (p-value ~ 0.0; 95% CI = 1.50–3.34), whereas engineers were 1.86 times more likely to agree (p-value = 0.0003; 95% CI = 1.27–2.72). Contractors on the other hand were 4.16 times more likely to disagree that contractual problems do not allow designers to practice DCWS (p-value ~ 0.0; 95% CI = 2.47–7.00).

Similarly, the legal area of obstacles was identified both by engineers and architects to be a concern. Architects were 2.22 more likely to agree (p-value ~ 0.0; 95% CI = 1.51–3.26), whereas engineers were 1.57 times more likely to agree (p-value = 0.0055; 95% CI = 1.09–2.26). On the other hand, contractors were 2.86 times more likely to disagree (p-value = 0.0004; 95% CI = 1.66–4.92).

The ethical area of obstacles was surprisingly only different for architects. Even though only 22.6% of architects agreed that there are ethical obstacles in place, they were still 3.01 times more likely to agree than all the other groups combined that ethical obstacles are in place (p-value ~ 0.0; 95% CI = 1.94–4.67). By contrast, contractors were 3.03 times more likely to disagree that there are ethical obstacles than all other groups combined (p-value ~ 0.0; 95% CI = 1.78–3.82). The last area of obstacles, cultural obstacles, also showed some differences among the responding groups. Specifically, architects were 1.44 times more likely to agree that there are cultural obstacles (p-value = 0.0195; 95% CI = 1.021–2.05), whereas contractors were 2.91 times more likely to disagree (p-value ~ 0.0; 95% CI = 1.97–4.30).

The same six areas that were considered for obstacles were also presented as possible enablers. Architects were 1.76 times more likely to disagree that there are regulatory enablers to allow designers to practice DCWS (p-value = 0.0015; 95% CI = 1.21–2.55) than all other groups combined. They were also 1.94 more likely to disagree that that there are economic enablers (p-value = 0.0002; 95% CI = 1.35–2.78), 1.89 times more likely to disagree regarding contractual enablers (p-value = 0.0003; 95% CI = 1.31–2.73), 1.92 for legal enablers (p-value = 0.0003; 95% CI = 1.33–2.77), 1.78 for ethical enablers (p-value = 0.0107; 95% CI = 1.11–2.86), and 1.87 for cultural enablers (p-value = 0.0069; 95% CI = 1.11–3.15). Architects showed the most disagreement compared with all other groups regarding the presence of any enablers for DCWS practice.

Research Limitations

Before proceeding to the conclusions of the paper, it is important to mention any possible limitations in this study. One limitation that might be of concern is the relatively low (21.6%) response rate to the survey. Such a response rate is reflective of the industry and online surveys in general. Online survey response rate was investigated by Cook et al. (2000), who observed that the average response rate was 39.6% with a standard deviation of 19.6%. Participants in the survey presented in this paper did not have any incentive to participate nor were required to participate by their professional organizations. The authors are confident that the results of the study are a good representation of the industry because participants from more than half of the U.S. states have been surveyed (29 of 50). In addition the survey, participants had a very diverse background, and the major industry key players (owners/contactors/designers) were represented in the study.

The owner group that was selected in the survey could be viewed as a group that is not representative of all owners. However, because universities commonly construct almost all types of buildings, practice a variety of project delivery methods, and are both public and privately owned, the experience shared by their employees in the survey was valuable to the research. To improve the quality of owner responses, a future study can include the input from other types of owners that would add knowledge in the DCWS topic from an additional perspective based on experience with a variety of project types and delivery methods.

The current paper focuses only on the status quo of the construction industry and the current knowledge of construction industry participants on the topic of PtD and DCWS. Any future research on the implementation of DCWS would need to consider the dynamics of the industry.

Conclusions and Recommendations

As observed from this survey, current knowledge of DCWS, and of the PtD concept in general, is not widespread in the U.S. construction industry. The authors believe that there is enough supporting experience and research available to generate interest and gradual practice of PtD in the United States.

Design Decisions and Safety Participation

One of the primary reasons that makes the authors believe that there is future for DCWS in the United States comes from the analysis of the survey responses, specifically, that design decisions can influence construction worker safety. The understanding that design decisions have an impact on construction worker safety is evident from the responses of all industry participants. For decisions made before design, the level of agreement that these decisions affect safety was 68.4% from engineers, 47.5% from architects, 59.5% from owners, and 81% from contractors. For decisions made during design, the level of agreement was 77.9% from engineers, 52.5% from architects, 66.2% from owners, and 86.6% from contractors (Fig. 2).

But this understanding is not enough to urge designers to practice DCWS. When asked for the possibility for designer and owner participation in safety, the response was more welcomed by engineers than architects. Engineers responded with 53.7% agreement that designers should practice DCWS, whereas only 25.8% of architects responded in agreement. A similar response from designers was observed when survey participants were asked about the possibility for owner participation in construction safety; 52.9% of engineers and 27.2% of architects agreed (Fig. 3). A reason for this low willingness to practice DCWS might be attributed to a variety of perceived obstacles that are discussed subsequently.

Obstacles to DCWS Participation

Both architects and engineers recognize that there are obstacles for DCWS implementation in three key areas: legal, economic, and contractual. The U.S. construction industry is highly litigious and deters designers from assuming the additional responsibility of considering construction worker safety in their designs. A future possible framework for the implementation of DCWS in the U.S. construction industry should take into account these concerns and protect designers from frivolous lawsuits. The economic obstacle identified by designers was primarily attributed to concerns that design costs increase if DCWS is implemented. The owner group that was surveyed did not recognize that there are economic obstacles, suggesting that there might be long-term benefits to DCWS implementation that outweigh any possible initial and unexpected costs attributed to increased design effort. Further research through a lifecycle cost analysis is suggested to investigate the potential long-term benefits of DCWS during construction, occupancy, and decommissioning. Traditional construction contracting might be viewed as a deterrent to DCWS participation. The architect group that participated in the survey stated with 59.3% agreement that current construction contracting does not allow designers to participate in construction worker safety. That percentage was 41.4% for engineers, 33.1% for owners, and 14% for contractors. Architects seem to require an additional incentive for them to practice DCWS, and that might only be possible by direct instruction from the owner group, which would provide the monetary compensation and the contractual requirements.

Generating Interest in DCWS

Responses from engineers and contractors were closely aligned to many of the responses of the survey. This alignment would suggest that engineers possess an understanding of construction operations, greater than that of architects, which allows them to have a more realistic viewpoint of the possible hazards and safety risks that are present on a construction job site. Increased understanding of construction operations can happen through collaboration among project participants. Alternative contracting methods that require an increased interaction between designers and contractors before construction, such as design-build and construction management/general contractor, allow designers to contribute to construction safety. In addition, designer education in construction safety is important. As observed in the survey results, the majority of the industry participants had no prior knowledge of the concept or did not believe that designers and owners had adequate opportunities to be educated in construction safety. It is suggested that universities with civil engineering and architecture programs incorporate constructability issues in their curricula that address construction worker safety. Also, practicing engineers and architects can be educated in construction safety through seminars and professional development classes that are currently available.

Supplemental Data

Survey questions are available online in the ASCE Library (www.ascelibrary.org).

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